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Department of the Navy
Naval Ordnance Test Station
Contract N123-60530S-3825A - T. O. 3

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STATIC FORCE AND MOMENT COEFFICIENTS
OF A PROPELLER STABILIZED AND A
FINNED TORPEDO SHAPE

Michael E. Slater

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Hydrodynamics Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

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Report No. E-78.1
June 1958

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ABSTRACT

Static force and moment coefficients were measured in the High Speed Water Tunnel on nonpowered models of a propeller-stabilized and controlled torpedo. The tests were made on three propeller configurations and four body-fin combinations. Representative tests were conducted over a range of tunnel velocities. Data are presented as functions of body angle of attack and propeller shaft deflection. A comparison is presented of the experimental data and the theoretical analysis of T. Lang of the Naval Ordnance Test Station, Pasadena.

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INTRODUCTION

Torpedoes which are propelled, stabilized and guided solely by propellers have been investigated theoretically by the Naval Ordnance Test Station in Pasadena. These studies combined with previous investigations of the characteristics of nonpowered, free-turning propellers provided the basis of a contract between the Test Station and the Hydrodynamics Laboratory for an experimental test program in the High Speed Water Tunnel of the Laboratory.

The propellers were designed by the Test Station, and, following joint selection of the tests, a series of models was constructed consisting of a single basic body configuration, three pairs of contrarotating propellers, and, for purposes of comparison, four sets of fixed stabilizing fins.

The initial stages of the program were planned by R. W. Kermeen, of the Hydrodynamics Laboratory, and T. Lang, of the Naval Ordnance Test Station. Mr. Kermeen was responsible for the over-all engineering and fabrication of the models, while Mr. Lang provided propeller design, suggestions for model parameter variation, and general theoretical guidance throughout the entire test program.

MODEL DESCRIPTION

The body used in all of the tests was a two-inch diameter model of the Mark 13 torpedo shape. To permit attachment of the fins and propellers, the afterbody was fitted with a one-half-inch diameter cylindrical extension two inches long. The resulting over-all length of the model was 16.995 inches. The cylindrical extensions used for the propellers were attached to the body at angles from zero to two degrees by short conical sections having different attachment angles.

Figure 1 is a photograph of the model equipped with the fins, with one-inch chord length. Below the model in the same picture are shown the fins with chord lengths of 0.6, 1.2, and 2.0 inches, respectively.

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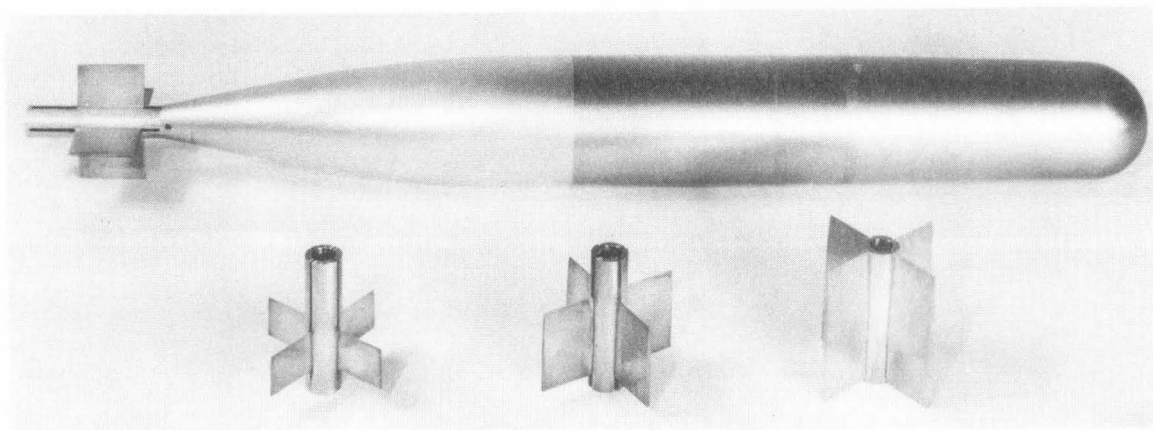


Fig. 1. The Mk 13 test body with the 1.0-inch chord length 2-inch diameter fins attached. In the foreground are the 0.6, 1.2, and 2.0-inch chord-length fins.

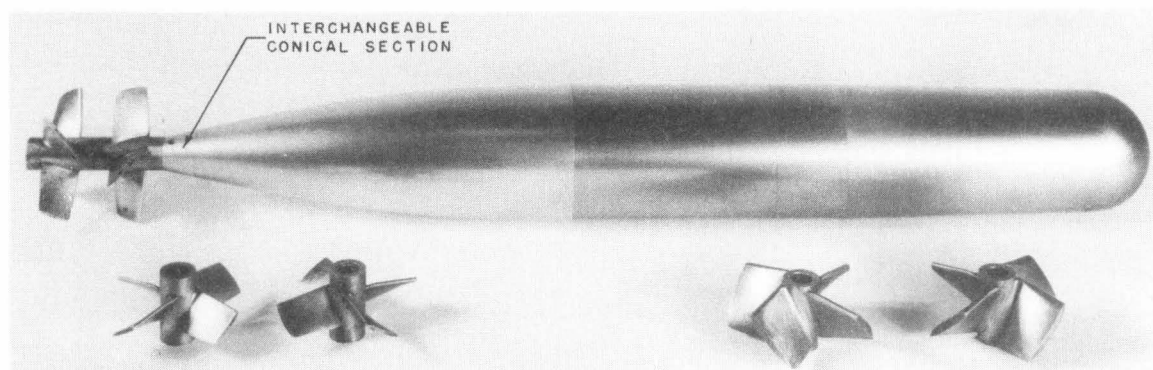


Fig. 2. The Mk 13 test body with the 0.6-inch chord length, advance ratio of 3, set of counter rotating propellers attached. In the foreground are the 0.6-inch chord-length advance ratio of 2 and the 1.0-inch chord-length advance ratio of 3 propeller sets. The interchangeable conical section was used to produce propeller shaft deflection angles.

The details of the fins are shown in Fig. 3.

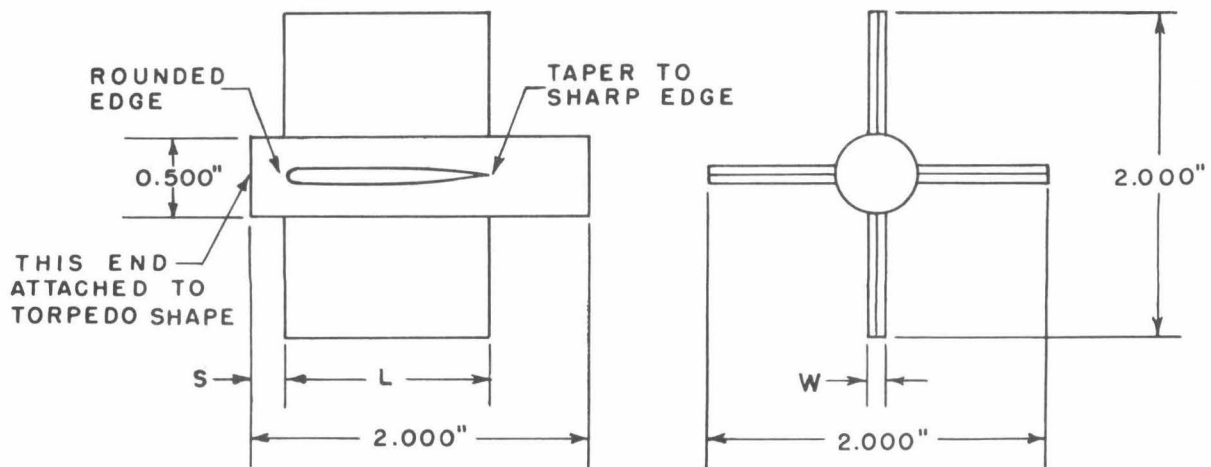
Figure 2 shows the model with the three pairs of counter-rotating propellers used in the tests. The propellers shown on the model have chord lengths of 0.6 inch and advance ratios of 3. The propeller hub dimensions are given in Fig. 4 and the pitch angles are given in Fig. 5. The profile of the blades was similar to that of the fins. It will be seen that the fins had areas that were approximately equal to either the blade area of one of the propellers in each pair or to the blade area of both propellers in a pair.

Bearings of Teflon, nylon, bronze and graphite were investigated before a choice was made for the propeller bearings. Water-lubricated graphite bearings were finally selected, since these gave the lowest friction and the least chatter of any of those tested.

TEST PROCEDURE

Static lift, drag, and pitching moment were measured as functions of body angle of attack in the High Speed Water Tunnel over a range of flow velocities. Every model configuration was tested at 30 fps, and representative runs were made at velocities of 20 and 40 fps. Additional drag data were measured for zero angle of attack for velocities of 5 to 60 fps. In all cases, duplicate runs with dummy support struts were made to permit linear correction of strut-caused flow interference. These corrections were applied to all of the force measurements and to the propeller speed measurements in the tests where the body angle of attack was zero, and the extension carrying the propellers was in line with the torpedo axis.

The effect of pitching the propeller axis relative to the body axis in the pitching plane was investigated by setting the afterbody extension that carried the propellers to angles of $1/2$, 1, $1-1/2$ and 2 degrees relative to the body axis. Propeller speed was determined by use of a General Radio strobotac.



DIMENSIONS IN INCHES			
SET NO.	L	S	W
1	0.600	.350	.030
2	1.000	.250	.050
3	1.200	.200	.060
4	2.000	.000	.100

Fig. 3. Fin dimensions.

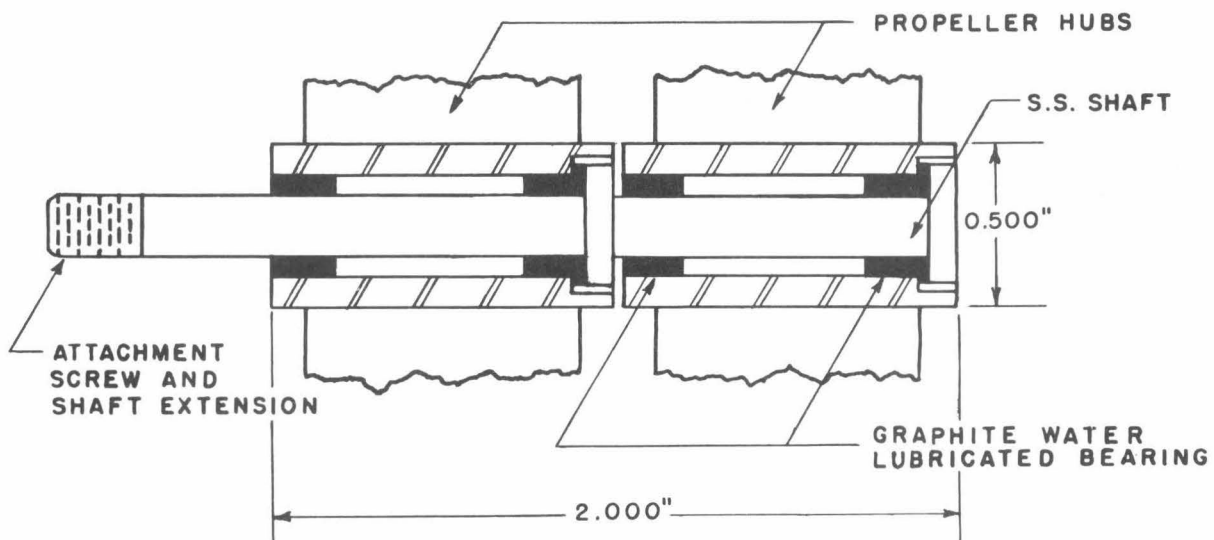


Fig. 4. Propeller dimensions.

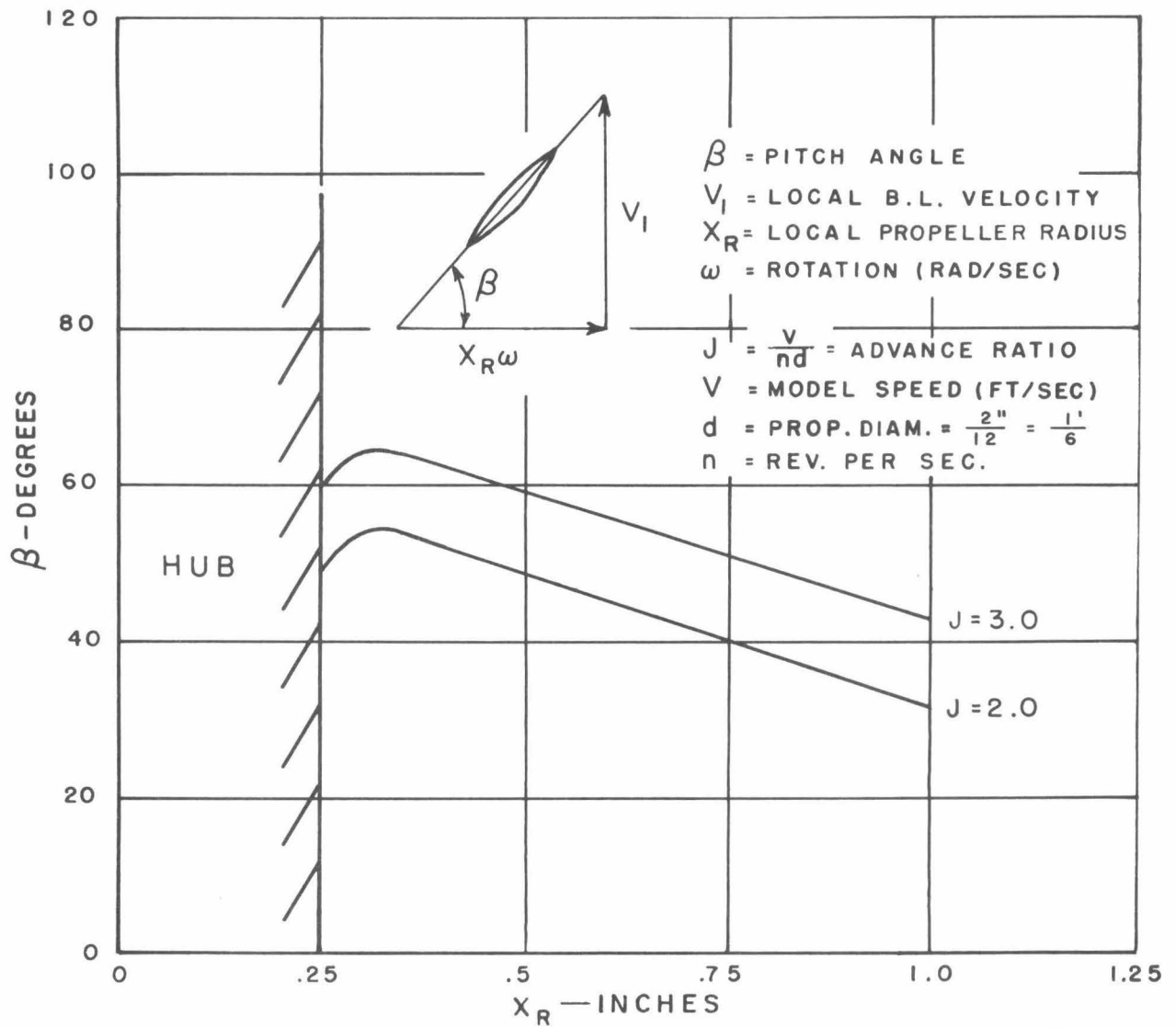


Fig. 5. Propeller construction data.

RESULTS

Preliminary theoretical investigations indicated that for purposes of torpedo guidance, propeller-shaft deflections of approximately two degrees maximum would give adequate control. Consequently, the test program was planned to yield static force coefficients near zero angle of attack ($\alpha = \pm 2^\circ$). The actual tests, however, were conducted over a much larger range of α . This was done to permit an investigation of possible instability due to large changes in force coefficients outside the region of immediate interest. The data are, therefore, presented in both graphical and tabular form.

All of the lift and moment coefficients near zero angle of attack are given in Table 1.

TABLE 1FORCE COEFFICIENTS FOR α NEAR ZERO

<u>Model</u>	$\frac{C_{L\alpha}}{\text{(per radian)}}$	$\frac{C_{M\alpha}}{\text{(per radian)}}$
Bare Body*	1.03	.974
Finned body		
0.6"	1.86	.630
1.0"	2.01	.663
1.2"	2.04	.566
2.0"	2.13	.521
Body with propellers attached		
J = 2; c = 0.6"	2.11	.477
J = 3; c = 0.6"	2.19	.433
J = 3; c = 1.0"	2.50	.371

* The force coefficients for the bare body are valid for the entire range of angles tested, $\alpha = \pm 8^\circ$.

Graphical presentation of these data for a wider range of angle of attack is made in Figs. 6, 7, 8, and 9, with the exception of the lift and moment coefficients of the bare body. These bare body coefficients were linear over the range of angles tested, and are reported as slopes only. Drag coefficient versus angle of attack curves are shown in Fig. 10. In addition, Fig. 11 presents drag coefficient at zero angle of attack as a function of Reynolds number. All of these data, along with the propeller rpm versus angle of attack curves, Fig. 12, were either measured directly or obtained by linear combination of pairs of test runs.

The effect of propeller axis deflection is shown in Fig. 13; the average slopes given for the sets of curves are also listed in Table 2. Each curve in each set of plots represents the effect of propeller axis deflection on the force coefficients for a constant angle of attack. As indicated, the range of investigation was $\pm 2^\circ$ for α and 0 to $+2^\circ$ for δ .

TABLE 2

A COMPARISON OF EXPERIMENTAL AND PREDICTED
FORCE COEFFICIENTS

Propellers		Values of the force coefficients, per radian			
		$C_{L_\alpha}^*$	$C_{M_\alpha}^*$	C_{L_δ}	C_{M_δ}
J = 2	Exp.	1.08	-0.50	1.24	-0.58
C = 0.6"	Theo.	1.08	-0.54	1.08	-0.54
J = 3	Exp.	1.16	-0.54	1.12	-0.58
C = 0.6"	Theo.	1.18	-0.59	1.18	-0.59
J = 3	Exp.	1.47	-0.60	1.61	-0.80
C = 1.0"	Theo.	1.62	-0.81	1.62	-0.81

*The force coefficient due to the bare body has been subtracted.

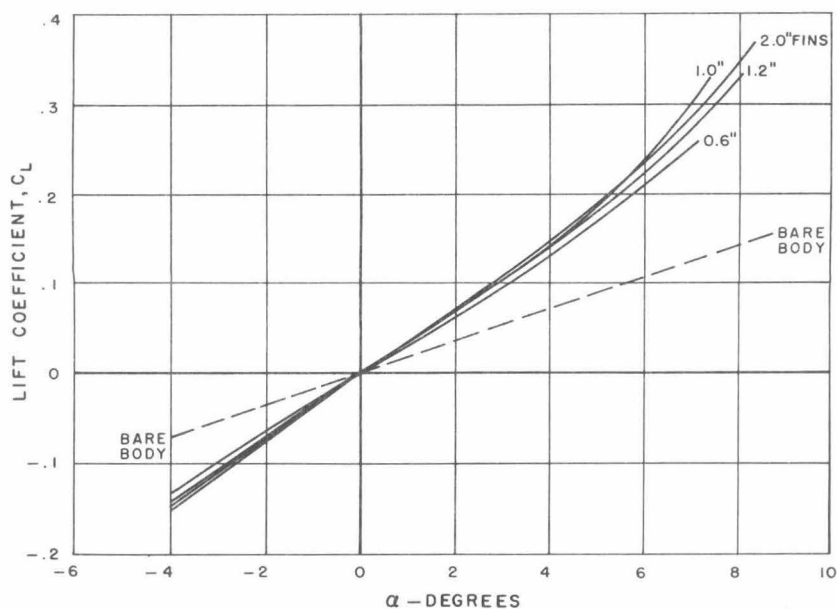


Fig. 6. Lift coefficient vs angle of attack for the several body-fin configurations. All data measured at tunnel velocities of 20, 30, and 40 fps.

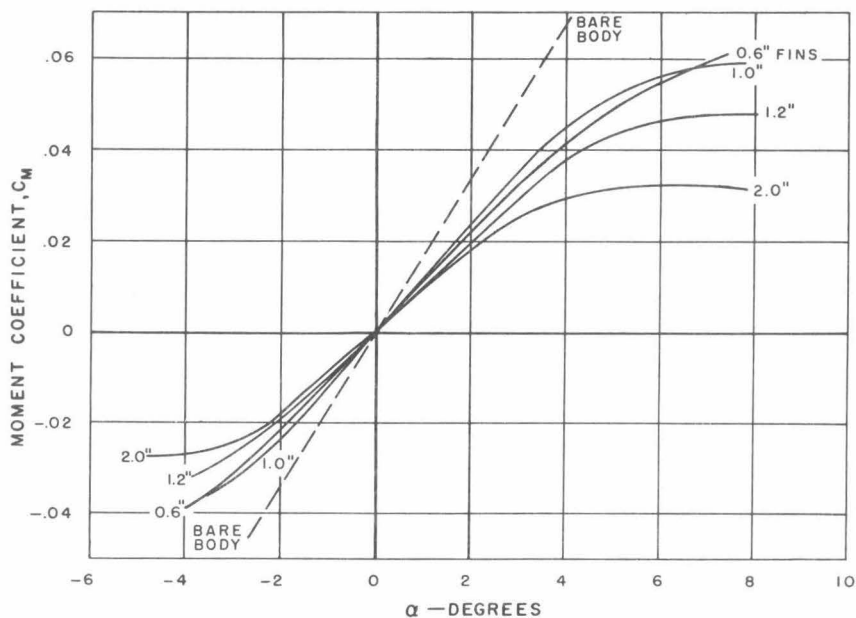


Fig. 7. Moment coefficient vs angle of attack for the several body-fin combinations. All data measured at tunnel velocities of 20, 30, and 40 fps.

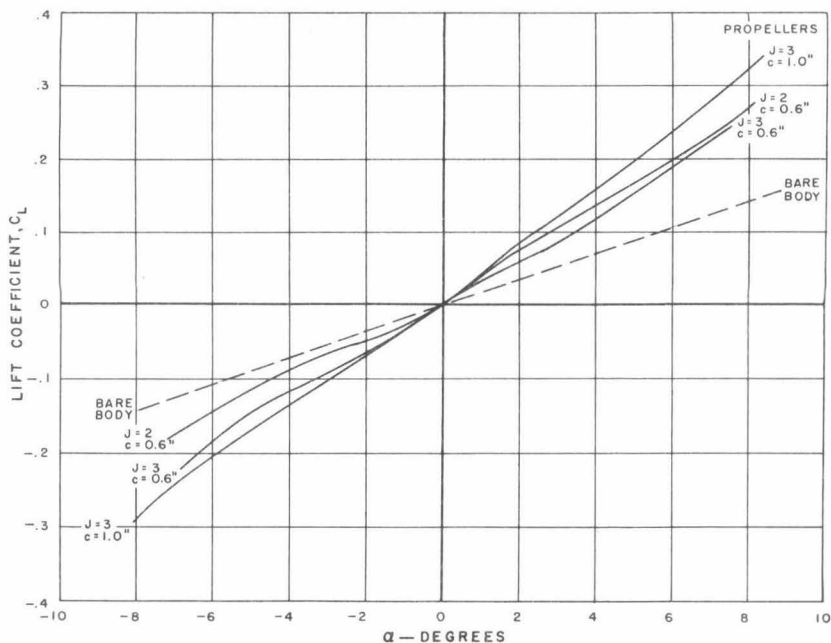


Fig. 8. Lift coefficient vs angle of attack for the several body-propeller configurations. All data measured at tunnel velocities of 20, 30 and 40 fps.

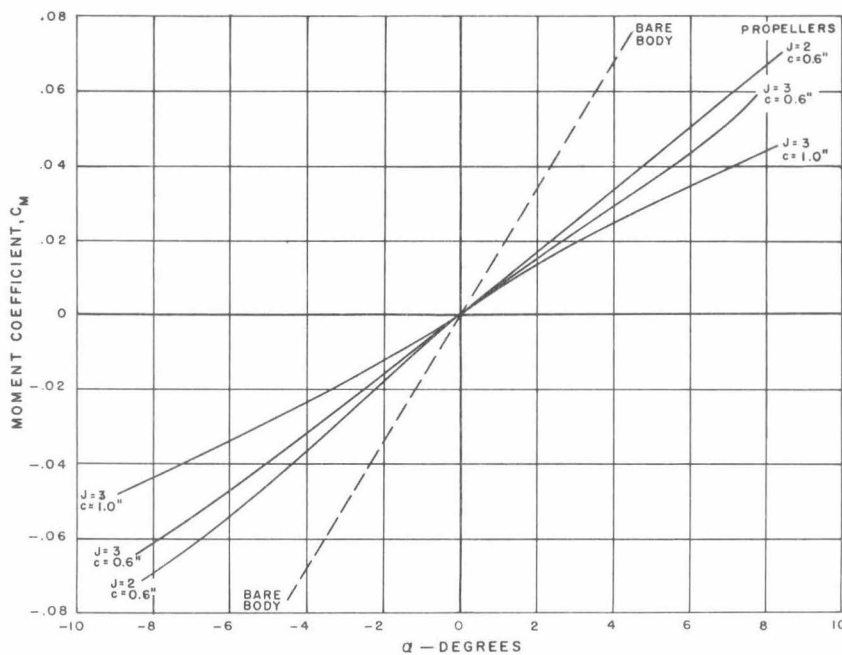


Fig. 9. Moment coefficient vs angle of attack for the several body-propeller configurations. All data measured at tunnel velocities of 20, 30, and 40 fps.

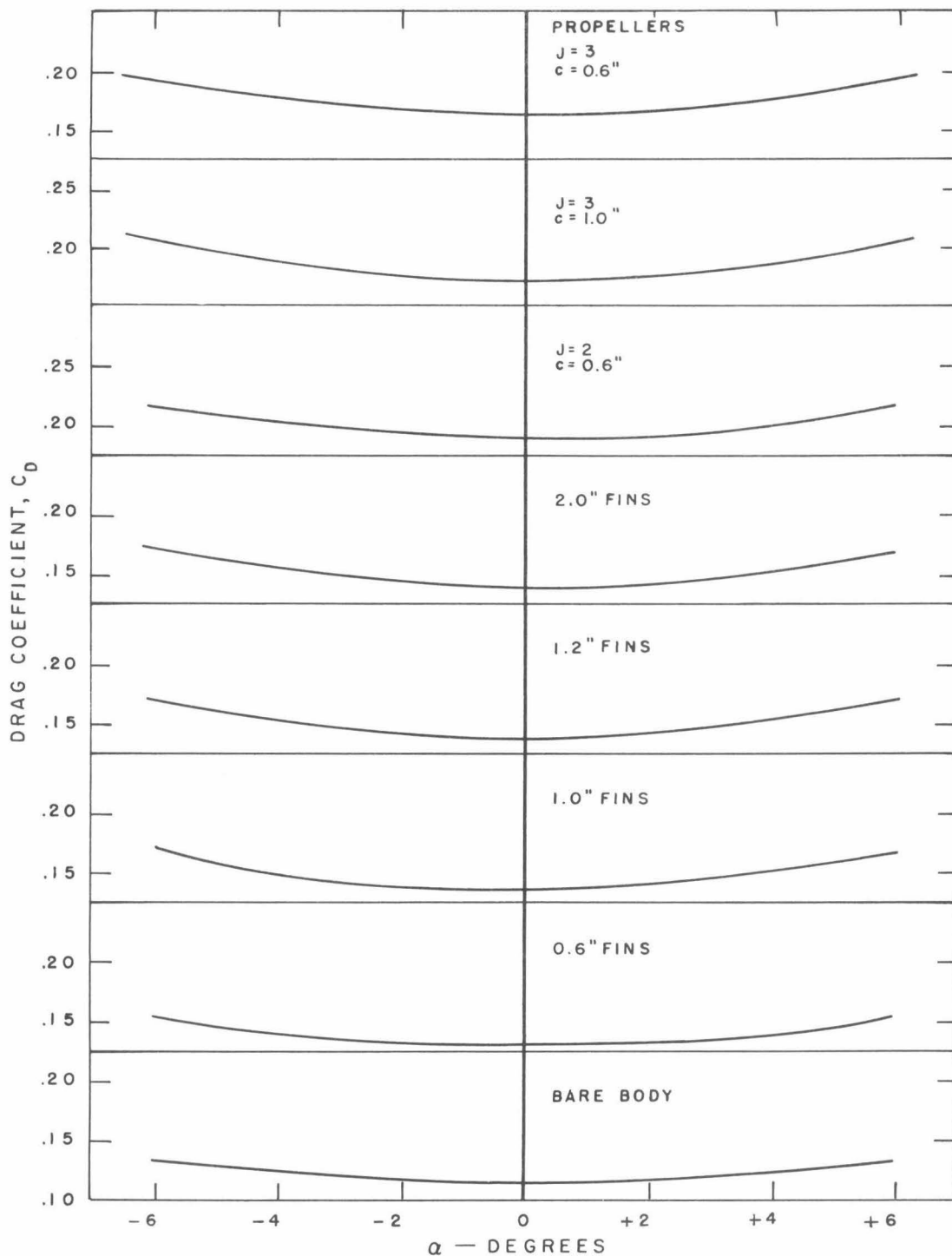


Fig. 10. Drag coefficient vs angle of attack. Tunnel velocity 30 fps.

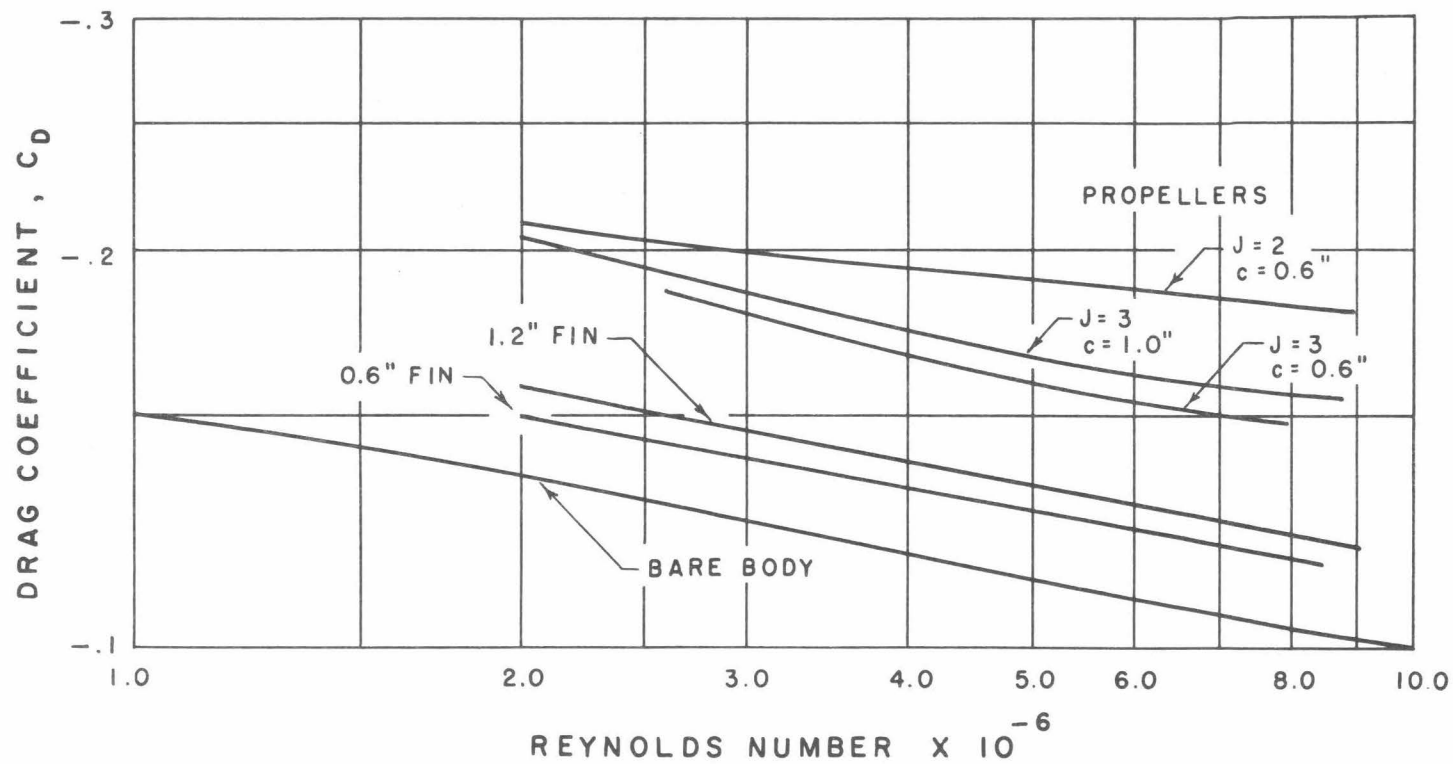


Fig. 11. Drag coefficient vs Reynolds number. $\alpha = 0^\circ$.

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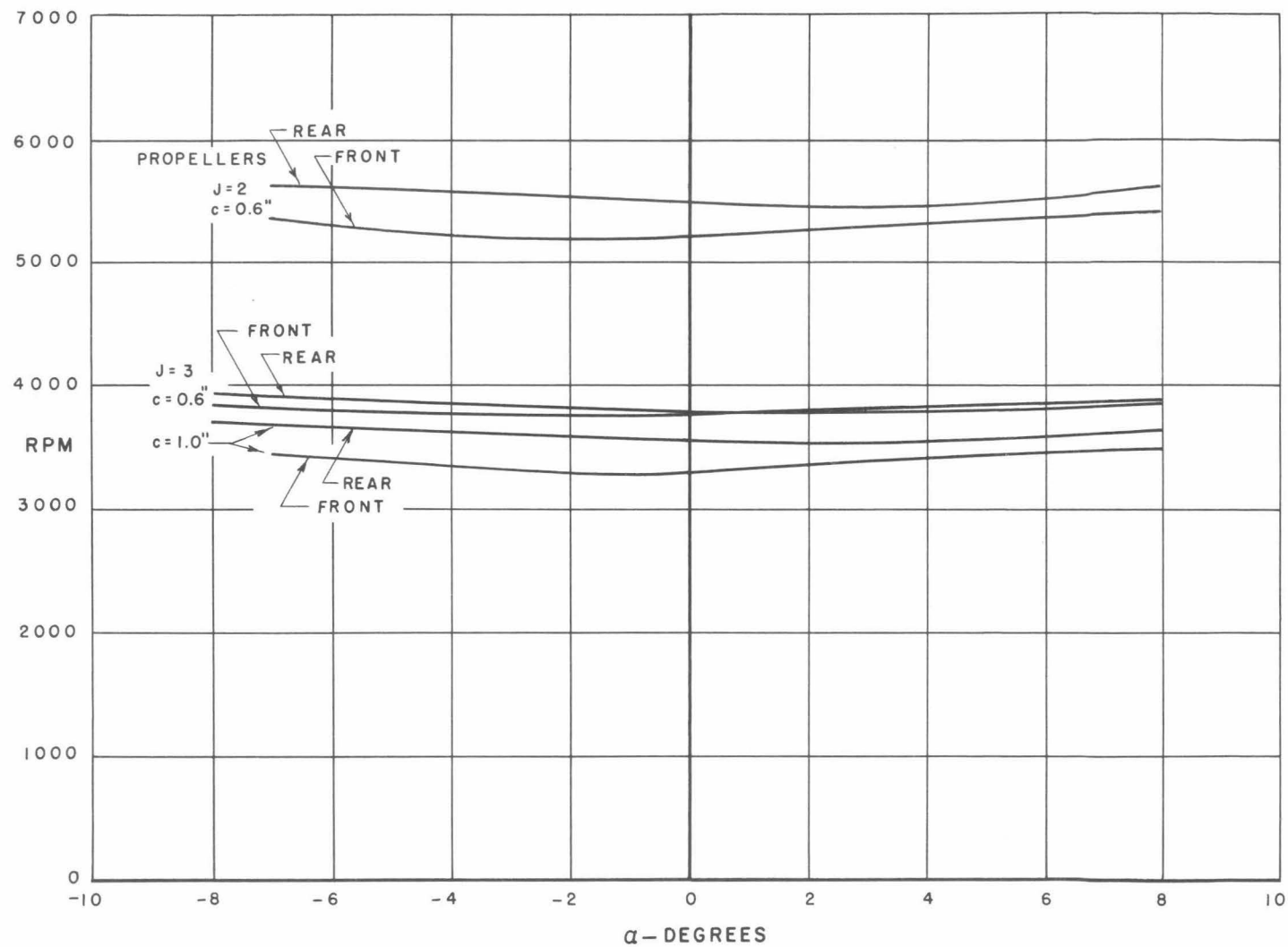


Fig. 12. Propeller speeds of both front and rear propellers as a function of body angle of attack. Tunnel velocity of 30 fps.

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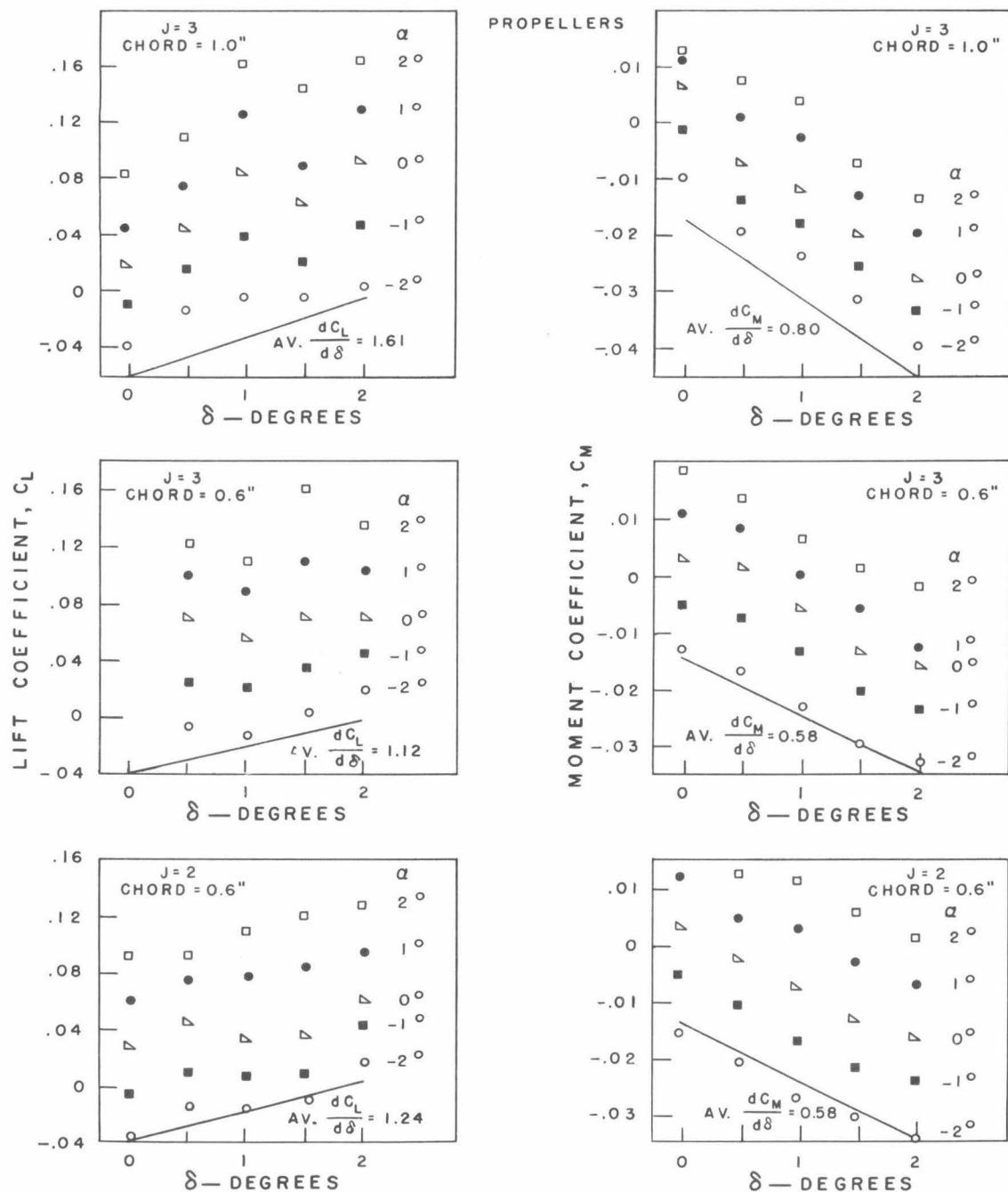


Fig. 13. Lift and moment coefficients vs propeller axis deflection angle (δ) for several values of body angle of attack (α). The average slopes are indicated graphically and the per radian slope value is given.

DISCUSSION OF RESULTS

The tests of each body configuration were, in general, carried out at tunnel velocities of 20, 30 and 40 fps. Comparison of the resulting force coefficient curves of any particular model yielded negligible differences between the several velocities tested, with the exception of drag coefficient. Therefore, the lift and moment curves presented are valid for all the velocities tested. The individual drag coefficient curves that are presented for both constant angle of attack and constant velocity can be combined to give the drag coefficient for any combination of velocity and angle of attack in the region tested.

Body tare force determinations made by testing the bare body resulted in lift and moment coefficient curves that were linear functions of body angle of attack. These tare coefficients were subtracted from the various propeller and finned body coefficient curves to yield the forces on the propellers and fins alone.

The several fin sizes tested, with the exception of the one-inch fins, provided a good comparison for the propeller data. The two-inch and one-inch fins were tested only at a velocity of 30 fps and for only one model installation. Probably the unreasonable data for the one-inch fins was due to mechanical interference between the support strut and its shield. Similar interference during the other test runs was not present because it would have been detected by the comparison made of the duplicate and similar test runs.

After the fin tests were completed, the propeller-body configurations were investigated for propeller speed as a function of tunnel velocity. These initial tests showed that the rear propeller, in general, rotated faster than the front propeller. This difference probably was due to the flow pattern around the body. Similar flow-pattern effects from the support strut were cancelled by the installation of an image strut. At zero angle of attack, the effect of these struts on propeller speed was evaluated and found to be negligible.

Using the data for zero angle of attack, experimental advance ratios were calculated and found to be very near the design values, as shown in Table 3. The experimental lift and moment were all compared with the theoretical values calculated by Lang (Ref. 1) and found to agree rather well (Table 3).

TABLE 3

<u>Propellers</u>		<u>Advance Ratios</u>	
<u>Blade Chord Inches</u>	<u>Design Values</u>	<u>Experimental Values</u>	
		<u>Front</u>	<u>Rear</u>
0.6	2	2.08	1.97
0.6	3	2.86	2.78
1.0	3	3.26	2.98

Propeller advance ratios calculated from propeller rpm data at 30 fps tunnel velocity and $\alpha = 0^\circ$. Corrected for support shield hydrodynamic interference.

The comparison of the measured effect of propeller axis deflection indicated that Lang's method (Ref. 2) predicts forces of the correct magnitude (Table 2). Further conclusions were not possible because the data reduction procedure resulted in increased scatter* that obscured better agreement. It must be noted, though, that in every case the predicted values were within the limits of data scatter.

*See Appendix.

ACKNOWLEDGMENT

The author wishes to acknowledge the contributions to the test program by R. W. Kermeen and T. G. Lang. In addition, he expresses his gratitude to Professor Vito A. Vanoni for his valuable suggestions and assistance during the writing of the report.

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1. Lang, Thomas G., "Windmilling Characteristics of Propellers", China Lake, Calif., NCTS, 10 May 1956. (NAVORD Report 5252, NCTS 1455).
2. Lang, T. G., "Propeller Stabilized and Controlled Torpedoes", China Lake, Calif., NCTS, 17 October 1956. (NAVORD Report 5368, NCTS 1602), CONFIDENTIAL

APPENDIX

ACCURACY OF THE FORCE COEFFICIENT DATA

Direct comparison of the uncorrected for shield interference data indicated that the $C_{L\alpha}$ scatter was at least several times greater than the corresponding $C_{M\alpha}$ scatter. The nature of the corrections applied to the data were such that the effect of the scatter was doubled in the final $C_{L\alpha}$ and $C_{M\alpha}$ curves. Both $C_{L\delta}$ and $C_{M\delta}$ were derived from $C_{L\alpha}$ and $C_{M\alpha}$ curves representing many test runs. This resulted in the scatter in the $C_{L\delta}$ and $C_{M\delta}$ curves being greater than the scatter in any one $C_{L\alpha}$ or $C_{M\alpha}$ curve. Estimates of the accuracy of the $C_{L\alpha}$, $C_{M\alpha}$, $C_{L\delta}$, and $C_{M\delta}$ curve points are given below:

$$C_{L\alpha} \pm 0.01, \quad \delta \text{ assumed constant}$$

$$C_{M\alpha} \pm 0.001, \quad \delta \text{ assumed constant}$$

$$C_{L\delta} \pm 0.02, \quad \alpha \text{ assumed constant}$$

$$C_{M\delta} \pm 0.002, \quad \alpha \text{ assumed constant}$$

DEFINITIONS OF TERMS

The force coefficients are defined as follows:

$$\text{Drag coefficient} = C_D = \frac{D}{1/2 \rho V^2 A}$$

$$\text{Lift coefficient}^* = C_L = \frac{L}{1/2 \rho V^2 A}$$

$$\text{Moment coefficient}^* = C_M = \frac{M}{1/2 \rho V^2 A l}$$

Lift and moment coefficients as functions of body angle of attack = $C_{L\alpha}$ and $C_{M\alpha}$

Lift and moment coefficients as functions of propeller deflection angle = $C_{L\delta}$ and $C_{M\delta}$.

* Figure 14 indicates the directions of positive lift and moment.

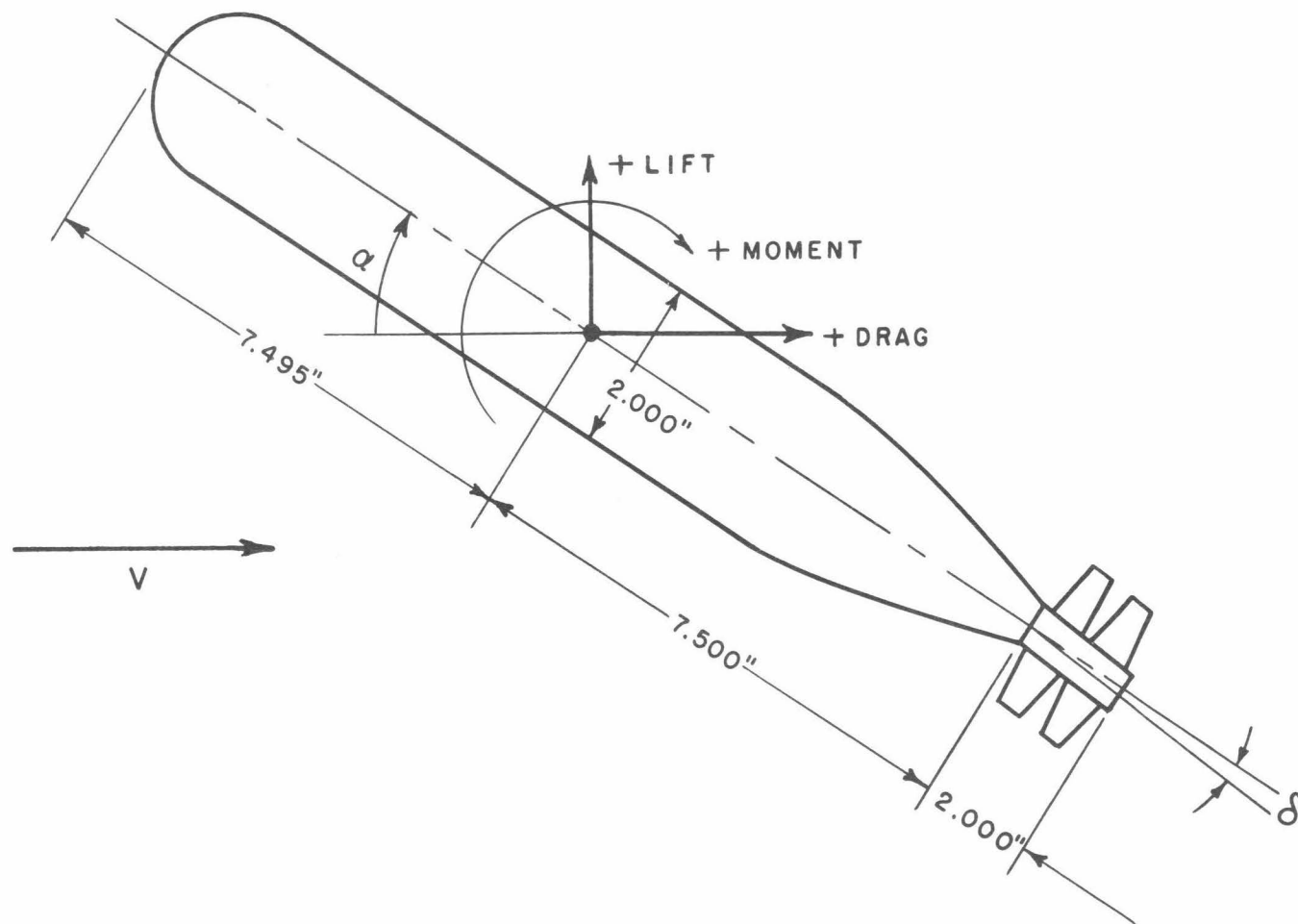


Fig. 14. Test body dimensions, directions of positive forces, and illustration of angles.

DEFINITIONS OF TERMS
(continued)

Reynolds number is defined as:

$$\text{Reynolds number} = \text{Re} = \frac{\ell V}{\nu} .$$

Propeller advance ratio is defined as:

$$\text{Calculated advance ratio} = J = \frac{V}{n d}$$

$$\text{Experimental advance ratio} = j = \frac{V}{N d}$$

The symbols used above indicate the following:

- A = maximum body cross-sectional area normal to the longitudinal body axis in sq. ft.
- D = total drag force in lb.
- C = chord length in inches.
- d = propeller diameter (was 2" for all propellers tested).
- L = total lift force in lb.
- ℓ = body length including 2-inch long afterbody extension.
- M = total moment about spindle in inch-lb.
- N = measured speed of propeller in revolutions per sec.
- n = no-slip speed of propeller in revolutions per sec.
- V = free stream velocity.
- α = attack angle, the angle between the longitudinal axis of the torpedo and the direction of water flow.
- δ = the angle between the centerline of the propeller shaft and the longitudinal axis of the body.
- ν = kinematic viscosity of water.
- ρ = density of water.